Title
DETERMINATION OF THE ENERGY DEPENDENCE OF THE FORM FACTOR IN Ke3 DECAY

Authors
Kalraus, George E.
Kiernan, Anne.

Publication Date
1966-08-20

Submitted to the XIII International Conference on
High Energy Physics, Berkeley, California,
August 27 - Sept. 7, 1966

UCRL-17087
Preprint c.2 repl.

UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory
Berkeley, California

AEC Contract No. W-7405-eng-48

DETERMINATION OF THE ENERGY DEPENDENCE OF THE FORM FACTOR IN K_{e3}^{+} DECAY

George E. Kalmus and Anne Kernan

August 20, 1966

UCRL-17087

Submitted to the XIII International Conference on High Energy Physics, Berkeley, California, August 27-September 7, 1966.

DETERMINATION OF THE ENERGY DEPENDENCE OF THE FORM FACTOR IN K^+_{e3} DECAY

George E. Kalmus and Anne Kernan

Lawrence Radiation Laboratory
University of California
Berkeley, California

August 20, 1966

EXPERIMENTAL DETAILS

We have studied the decay

$$K^+ \to \pi^0 + e^+ + \nu, \quad \pi^0 \to 2\gamma \to 2e^\pm \qquad (1)$$

using stopping K^+ mesons in the Berkeley 30-inch heavy liquid bubble chamber. The chamber filling was freon, C_3F_8, having a density 1.22 gm cm^{-3} and radiation length 28 cm. A total of 250 000 pictures containing 2.9×10^6 stopped K^+'s was taken.

The film was scanned for K_{e3} decays that satisfied the following criteria:

1. The positron from the K^+ decay went through a maximum radius vector without change of ionization.
2. Two electron-positron pairs pointed back to the K^+ decay point on all three stereo views.
3. Neither of these pairs was tangential to the positron near the origin.
4. The K^+ ionization was consistent with a decay at rest, and there were no kinks or changes of ionization along the incoming K^+ track within 1 cm of the origin.

Condition 1 ensured that the charged secondary was unambiguously identified as a positron. Condition 3 eliminated events in which one of the pairs was due to a bremsstrahlung from the decay positron. This criterion may eliminate some genuine events. We have calculated the magnitude of this effect and find it small compared to the statistical error. Condition 4 largely eliminated a background contamination of τ' and $K_{\mu 3}$ decays for which the $\pi^+\mu^+$ chain or μ^+, respectively, were less than 1 cm.

All the tracks from the decay were measured by means of the Behr-Mittner method for calculating the momenta and errors. A two-constraint fit for the K_{e3} hypothesis was made for each event. A total of 529 events, from 30% of the film, fitted the hypothesis.

COMPARISON OF THEORY AND EXPERIMENT

The most general form of the matrix element for K_{e3} decay is

$$M \propto \sum_j \bar{u}_\nu O_j u_e A_j ,$$

where the O_j's are the Dirac matrices corresponding to the three possible types of coupling, scalar, vector, and tensor, and $\bar{u}_\nu O_j u_e$ is the lepton current. The strong-interaction currents A_j are of the form:

Scalar $A_j \propto f_s$

Vector $A_j \propto f_+ (P_k + P_\pi) - f_- (P_k - P_\pi)$

Tensor $A_j \propto f_t P_k P_\pi$.

The P's are 4-momenta, and the f's are dimensionless form factors that depend on the pion energy alone.

We compared the experimental distributions with the distributions expected for a pure vector, pure scalar, and pure tensor interaction. We also measured the energy dependence of the form factor f_+, for the assumption of a pure vector interaction.

The theoretical distributions cannot be compared directly with the experimental distributions. It is first necessary that the experimental errors and biases be folded into the theoretical distributions. This was done in two steps:

(i) For each hypothesis, 20 000 K_{e_3} decays were generated in a Monte Carlo program. The measurable quantities of each event were modified according to the known measurement errors. The event, thus modified, was constrained to the reaction (1) hypothesis.

We observed that the distributions of the constrained variables were systematically shifted from the theoretical distributions. This is illustrated in Fig. 1 which shows the lepton momentum distributions for 20 000 events generated according to a pure vector interaction. In a vector interaction the lepton distributions are identical; a real difference between the electron and neutrino momentum spectra would indicate a scalar-tensor interference term in the matrix element. The shift in the constrained variables is due to the large measurement errors, about 30% for the electron momentum.

(ii) Each constrained event was assigned a weight $P(E_p, E_\pi)$ which is the probability that the generated event would satisfy the four scanning criteria laid down for the experimental events. The function $P(E_e, E_\pi)$ is strongly energy dependent, since the positron detection efficiency varies from 100% at $E_e = 0$ to 30% at $E_e = E_{max}$.

The theoretical distributions in Figs. 2, 3, 5 and 6 were all obtained from 20 000 Monte Carlo events processed through steps (i) and (ii), above.

In Fig. 2 the experimental distribution in cos α is compared with the distributions predicted for pure vector, scalar and tensor. The distribution in cos α (the angle between the direction of the neutrino momentum in the dilepton center-of-mass system and the direction of the pion) is independent of the energy dependence of the form factors and provides a sensitive test of the nature of the interaction. Only the vector interaction hypothesis gives a reasonable fit with a χ^2 probability of better than 5%. A small admixture of scalar and/or tensor cannot be ruled out.

If the coupling in K_{e_3} decay is pure vector, the distribution in pion momentum is:

$$N(P_\pi)\, dP_\pi \propto f_+^2 \frac{P_\pi^4}{(P_\pi^2 + M_\pi^2)^{1/2}}\, dP_\pi \qquad (2)$$

and hence can be used to investigate the energy dependence of the form factor f_+. The term containing f_- is negligible in K_{e_3} decay. The form factors are functions only of the 4-momenta transfer $q^2 = M_K^2 + M_\pi^2 - 2\, M_K\, E_\pi$, and are relatively real if time reversal invariance holds in the decay. It is conventional to parameterize f_+ as $1 + \lambda\, q^2/M_\pi^2$ or alternatively in the form $1/(M^2 - q^2)$ where M is the mass of an appropriate J = 1 intermediate $K\pi$ state. By fitting the experimental pion momentum spectrum (Fig. 3) with equation (2) we obtain $\lambda = .09^{+.5}_{-.35}$ and M = 540 ± 90 MeV. Figure 4 shows the corresponding χ^2 (for 9 degrees of freedom) as a function (a) of λ and (b) of M, respectively.

In Fig. 3, equation (2) with $f_+ = 1/(M^2 - q^2)$, M = 540 MeV, is compared with the experimental pion momentum distribution. Figures 5 and 6 show the experimental lepton distributions, and the corresponding theoretical distributions for a pure vector interaction and M = 540 MeV.

Figure Captions

Fig. 1 Mutilated lepton momentum distributions for a pure vector interaction. They were obtained by generating 20 000 vector decays, folding in the measurement errors, and constraining each event to the K_{e_3} hypothesis. The constrained variables are plotted here.

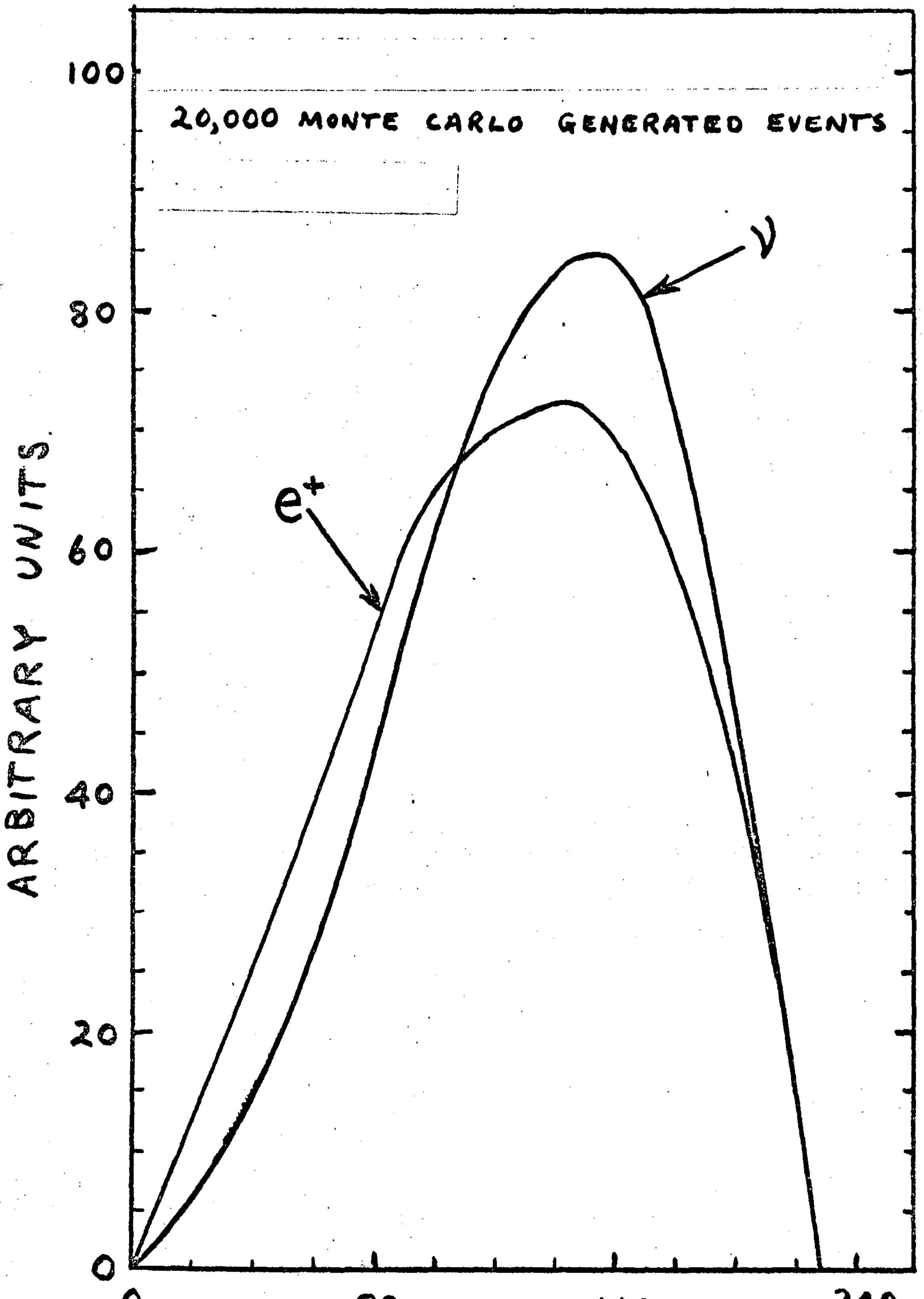
Fig. 2 Histogram of cos α. The smooth curves are the distributions predicted for a pure vector, scalar, and tensor interaction.

Fig. 3 Experimental pion momentum spectrum. The smooth curve is calculated for a pure vector interaction and form factor $f_+ = 1/(M^2-q^2)$, with M = 540 MeV.

Fig. 4 The χ^2 for 9 degrees of freedom, obtained by fitting the pion momentum spectrum by equation (2), with (a) $f_+ = 1 + \lambda\ q^2/M_\pi^2$, and (b) $f_+ = 1/(M^2-q^2)$.

Fig. 5 Histogram of positron momentum. The smooth curve is the prediction of a pure vector interaction and $f_+ = 1/(M^2-q^2)$, with M = 540 MeV.

Fig. 6 Same as Fig. 5 for the neutrino momentum.



20,000 MONTE CARLO GENERATED EVENTS
100
80
60
40
20
0
ARBITRARY UNITS
ν
e+
0
80
160
240
Plepton (MeV/c)

FIG 1

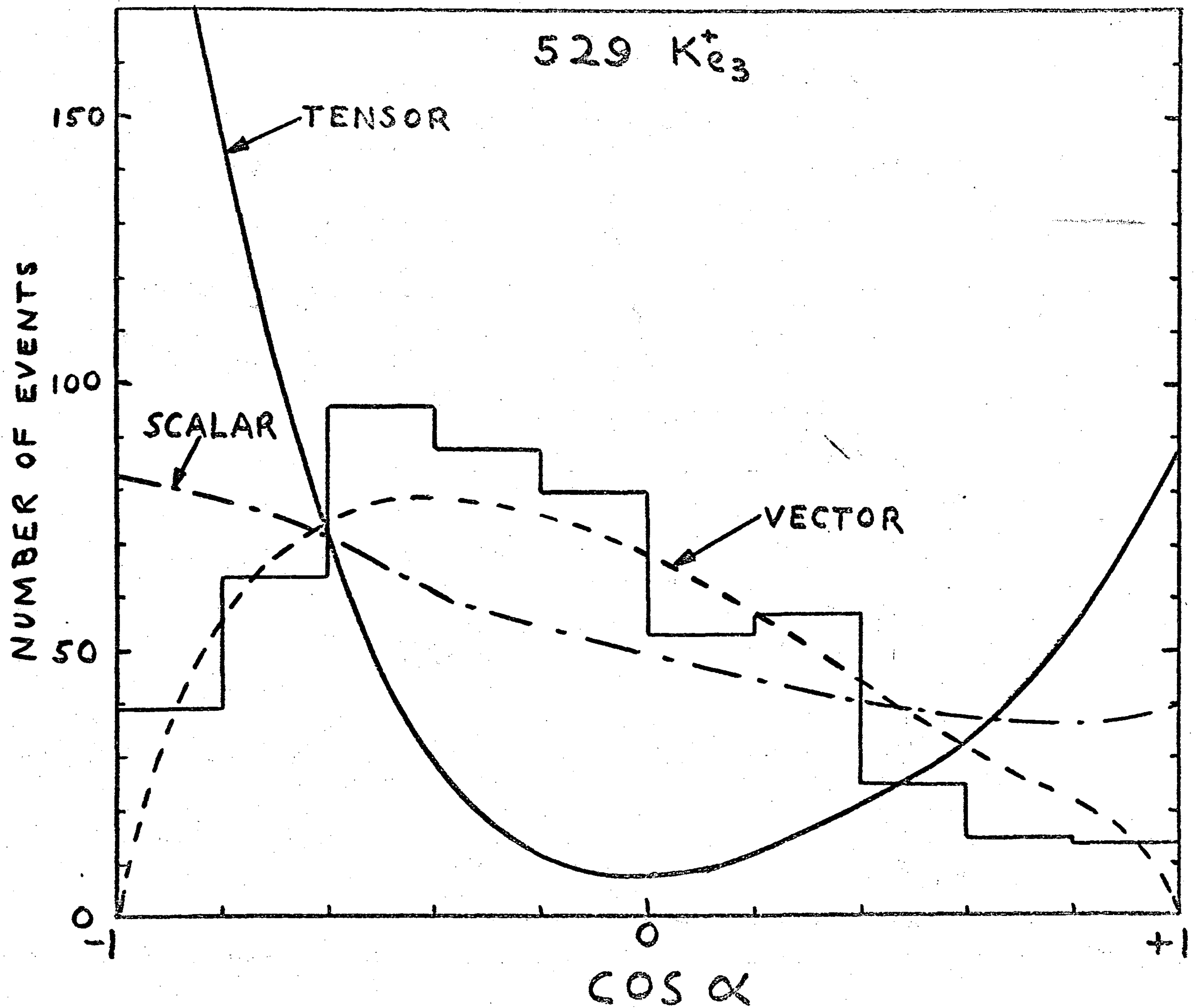
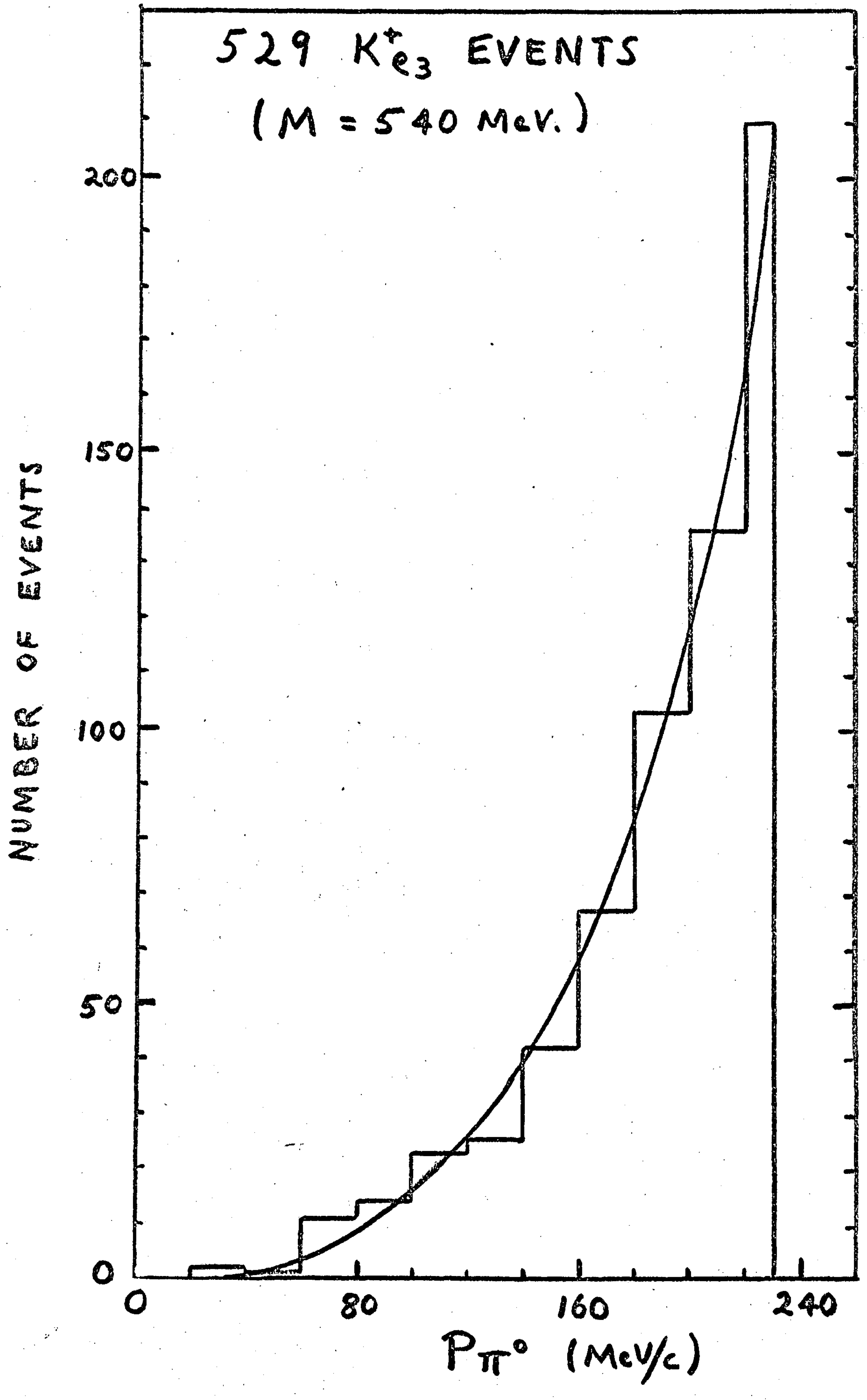
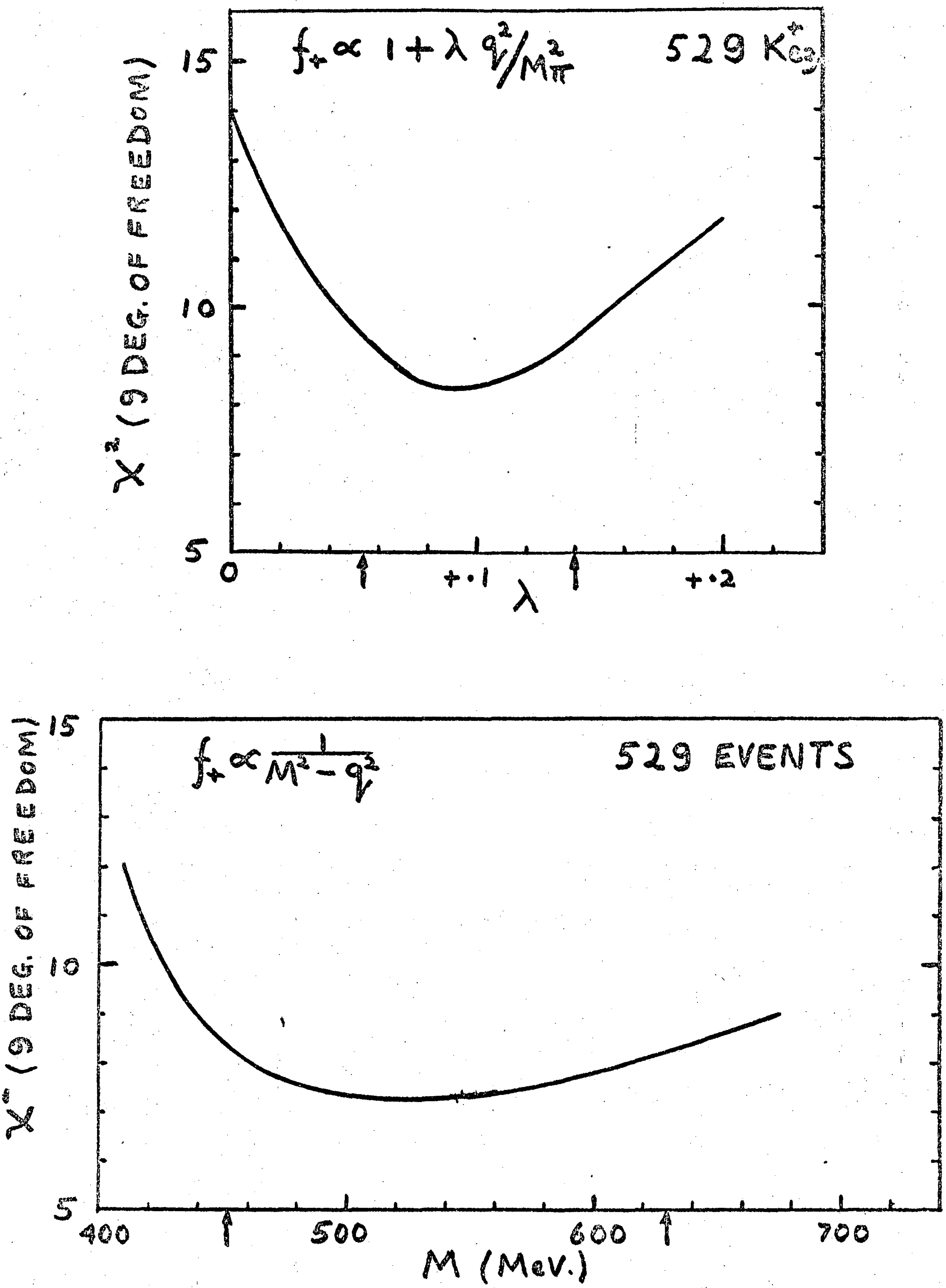

529 K^+_{e3}
TENSOR
SCALAR
VECTOR
NUMBER OF EVENTS
150
100
50
0
-1
0
+1
COS α

FIG 2



529 K^+_{e3} EVENTS
(M = 540 MeV.)
NUMBER OF EVENTS
0
50
100
150
200
0
80
160
240
P_{π^0} (MeV/c)

FIG 3



$f_+ \propto 1 + \lambda q^2/M_\pi^2$
529 K^+_{e3}
χ^2 (9 DEG. OF FREEDOM)
15
10
5
0
+·1
+·2
λ
$f_+ \propto \frac{1}{M^2 - q^2}$
529 EVENTS
χ^2 (9 DEG. OF FREEDOM)
15
10
5
400
500
600
700
M (MeV.)

FIG. 4

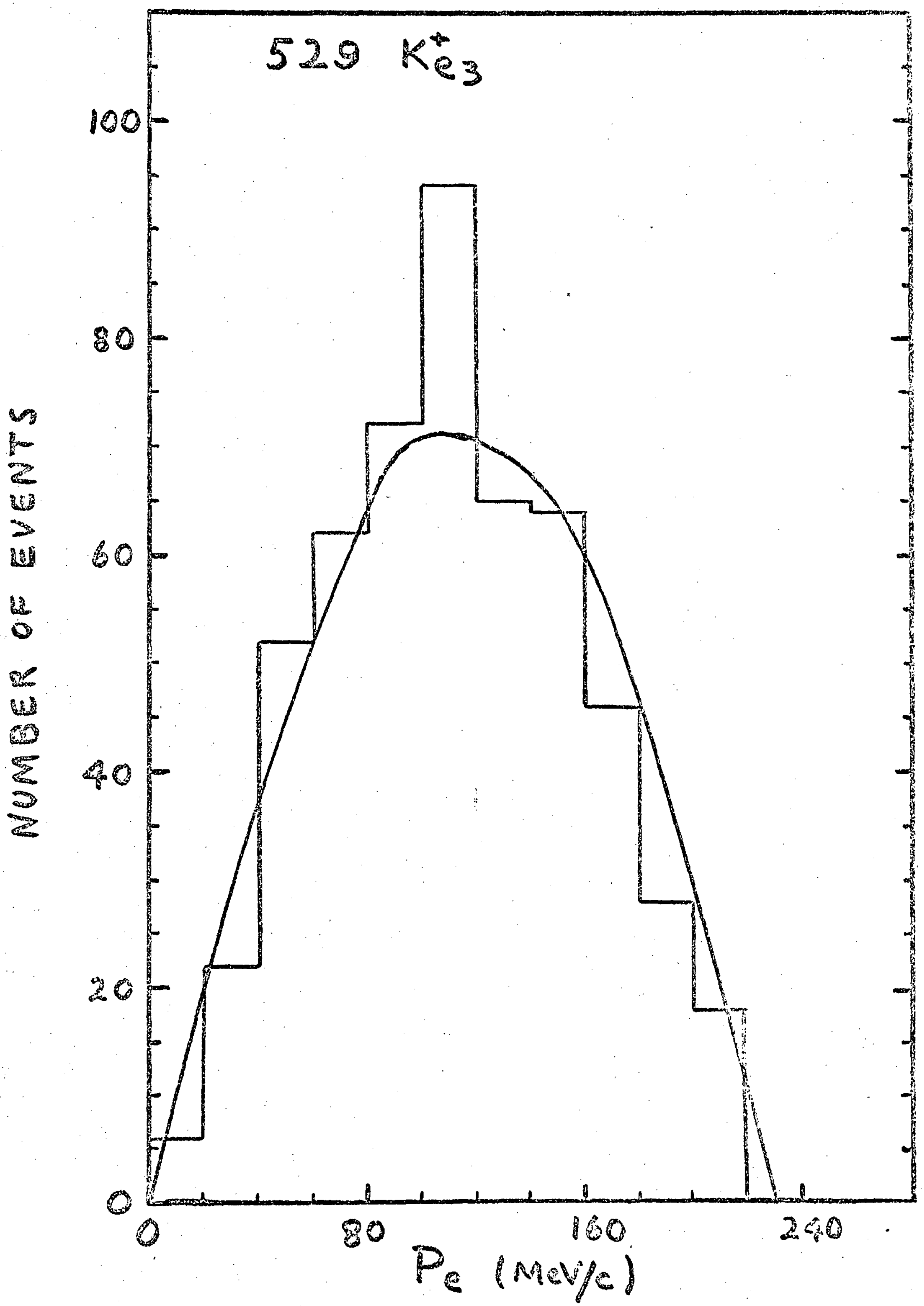
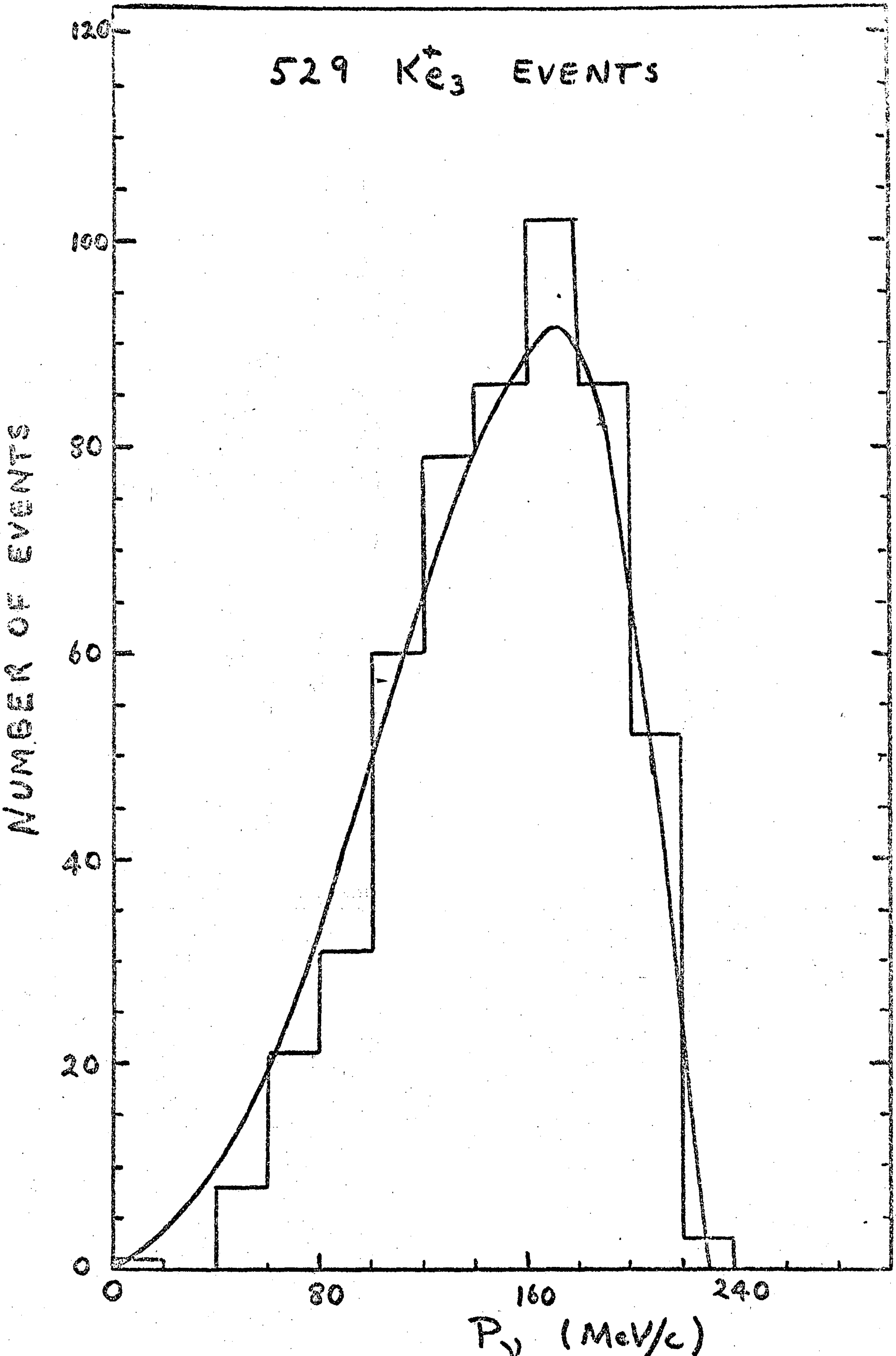


Fig 5


529 K^+_{e3} EVENTS
NUMBER OF EVENTS
120
100
80
60
40
20
0
0
80
160
240
P_ν (MeV/c)
FIG 6